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13. Abstract

LONG TERM RESEARCH OBJECTIVE:
Although marine mammal middle and inner ears are similar to those of land mammals, there are sufficient differences that marine ear damage mechanisms continue to be a hotly debated topic. To date there are surprisingly few direct investigations of marine mammal ear functions. While this project has an immediate goal of investigating intense pressure effects, it will also provide new data on both the structure and mechanical responses of a wide variety of marine ears. Therefore, in terms of basic research and the long-term goals of this field project, this work is expected to provide fundamental information that will improve our understanding of middle and inner ear response mechanisms specific to marine mammals.
S&T OBJECTIVES: The explicit objective of this research is to determine the dynamic range of mechanical responses of cetacean and pinniped ears to intense pressure sources. Ears are the bell weathers of pressure-induced damage. Equally important, they are a crucial sensory system for marine mammals. Therefore, understanding differential impacts on marine mammal ears from a range of received pressures, will provide a marine specific metric for determining blast and impulse noise exposure safety zones.

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APPROACH:
Cetacean and land mammal ears differ in their robustness, stiffness, mass, vascularization, and pneumatization characteristics. Therefore, it is not possible to accurately extrapolate whale or seal auditory system responses to blast or impulse pressures from existing experimental results on air-adapted ears. These experiments are designed to provide direct measures from marine auditory systems of intense pressure responses. Although responses in live animal would clearly give us the most accurate measures of damage and recoverability from blast exposures, for many reasons, these measures are not feasible for most marine mammals. However, based on the work of Rosowski et al, post-mortem ears, given proper handling and preservation, have been shown to have *mechanical* responses that are isomorphic with those of live ears. Because hearing loss and auditory system trauma from blasts and intense, short-term impulsive sources depend essentially upon mechanical responses of ear components, some of these effects are inducible and measurable post-mortem. Therefore, in this project, carcasses of stranded marine mammals are first examined post-mortem by CT to assure normal ear structures. The ears and post-cranial organs that are susceptible to pressure damage are then implanted with pressure gages. The implanted, intact specimen is immersed in a test pond, exposed to a single blast designed to deliver received pressures ranging from 300 to 0 psi, re-examined by CT to document gross tissue changes, and, finally, fully necropsied to assess structural damage at the cellular and infrastructural level. All scans are video or still photo documented and blast sequences are filmed using ultra-high speed video to confirm the position and overt reaction of the specimen to the pressure wave as well as to graphically document pre and post-exposure external condition of the specimen. All necropsies are documented on film and by digital camera. Although auditory system effects are the focus of the exam, all body tissues are documented.

S&T COMPLETED:
The following experiments have been completed since the grant's activation in Jan. 1999:
1) Four preliminary test pond mapping shots were performed to test the resilience of the specimen suspension system and to confirm received pressure model simulations for expected specimen placements within the test pond.
2) Two specimen simulation tests utilizing gages implanted in hams and two simulated cetacean ear tests were performed to confirm *in situ* gage integrity when implanted in soft tissues, in flexible air cavities, and at bone-soft tissue interfaces. For the latter tests, four pseudo-cetacean ears were constructed of acrylic shells equivalent to the volumes of small delphinid and larger baleen ears. Each shell was filled with varying combinations of flexible or semi-rigid walled air-cavities (balloon catheters or acrylic chambers), hydrated soft tissue only, and air only chambers. 3) Five actual tests of porpoise and dolphin post-mortem specimens have been conducted with gages implanted in the ear, esophagous, and hypaxial musculature. The specimens were tested at 300 psi (1 animal), 200 psi (1), 100 psi (2), and 50 psi (1) received pressure at the animal's surface. High received pressures were purposely chosen for the initial tests to test the feasibility of the measures and to determine how well the gages would respond in actual tissues.
The results of the blast tests to date are as follows:

(1) Tests without target specimens confirmed pressure simulations for the blast test pond are correct for pressures down to 25 psi and showed that the suspension rigging would withstand the test pressures anticipated without compromising received psi measurements.
(2) Simulated ear and tissue tests provided data for improvements in gage design and acted as trials for video equipment placement. These preliminary tests were required because the rarity and delicacy of appropriate postmortem specimens requires optimizing all recording equipment parameters prior to actual tests.
(3) Actual specimen test data are still considered preliminary but are encouraging. As a control, all specimen necropsies are performed and documented by AFIP-trained forensic and blast pathologists who are not privy to the received levels. Necropsy findings for the specimens examined to date show distinct and unequivocal damage consistent with - and only with - blast effects. The injuries sustained by all specimens at high psi (e.g., peri-bullar, intra-cochlear, and intracranial hemorrhage, subluxated ossicles, lung and liver disruption and hemorrhage) were profound and likely mortal, but, interestingly, the severity and number of impacts clearly decreases with psi and was consistent with mass-dependent predictions from previous studies on land mammals.

In summary, the test pond has been fully mapped; all apparatus tests were completed; and five full specimen tests have been completed. The specimen tests show graded damage that is inversely related to specimen mass. Suites of damage (number of organs involved, severity, etc) are consistent with received pressure and orientation of the specimens. In addition, some organs, including blubber, jaw fats, and melons, that are unique to cetaceans are differentially impacted based on received psi and may serve as diagnostic correlates for blast injuries. We expect that not only will these experiments provide conservative estimates of auditory trauma, but also that the data may provide a basis for calculating continual dose-damage curves for multiple marine species.

IMPACT/NAVY RELEVANCE:
The Navy is required to mitigate effects on marine mammals from blasts required for ship shock trials as well as other explosive and impulse sources. Currently, mitigation zones are being set by inference from land mammal experiments because we lack explicit data on pressure effects in marine mammals. As noted above, ears are vital sensory organs that are also primary indicators for pressure damage. By directly measuring and monitoring pressure damage in marine mammals and finding the endpoints for pressure-induced trauma, this project will provide the navy with the necessary baseline data for accurate aquatic mitigation zones.

PLANNED RESEARCH EFFORTS:
A minimum of 10, maximum of 20, specimens are expected to be tested, ranging from small cetaceans through larger pinnipeds, with replicate runs at 300, 200, 100, 50, 25, 10, and 0 psi, as required, to determine zones (based on received psi) of lethality, recoverable injury, permanent, temporary, and no significant functional auditory damage.